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PRELIMINARY EASTERN INDIAN OCEAN GEOID FROM GEOS-3 DATA, (U)

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by

SAMUEL L. SMITH, III

ALAN C. CHAPPELL

Warfare Analysis Department

JUNE 1977

NAVAL SURFACE WEAPONS CENTER

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NSWC/DL TR-3668
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Samuel L. Smith, III
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APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

(See 1473)

FORWORD

This work was performed in the Ocean Geodesy Branch, Astronautics and Geodesy Division of the Warfare Analysis Department, NSWC/DL. The authors wish to acknowledge the work of L. Beuglass, M. Douglas and their group in providing orbit ephemerides and the work of G. West, T. Hicks, R. McDaniel and V. McCracken for preliminary filtering and reduction of the radar altimetry data to along track sea surface height. Appreciation is also extended to Dr. J. G. Marsh of NASA/Goddard Space Flight Center for providing the Marsh and Chang 1976 Geoid used for comparison, and Dr. T. Davis of the Naval Oceanographic Office for providing the bottom topography charts of the Indian Ocean. This report was reviewed by R. J. Anderle of the Astronautics & Geodesy Division.

RELEASED BY:

Ralph A. Niemann

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CONTENTS

FIGURES

TABLES

INTRODUCTION

The use of satellite radar altimeter measurements to derive an ocean geoid that contains geoid undulation information at much shorter wavelengths than can be obtained from classical analysis of satellite orbit perturbations has been postulated for a number of years, e.g. references 1 and 2. Some experiments in this direction were carried out with radar altimeter data from Skylab, e.g. references 3 and 4, but the amount of Skylab radar altimeter data and the lack of accuracy of the Skylab orbital ephemerides precluded geoid determination over any appreciable area.

The GEOS-3 satellite was launched on 9 April 1975, carrying a radar altimeter with both short pulse and long pulse capability, laser retroreflectors and a Doppler beacon to allow precise orbit determination. GEOS-3 has produced radar altimeter data of both good quality and quantity for over a year. Both theoretical studies, reference 5 and preliminary evaluations, reference 6, of the GEOS-3 data showed that the short pulse radar altimeter data had a lower noise level than the long pulse data and would result in more precise derived geoids.

This paper develops the preliminary derivation of a local geoid in the Eastern Indian Ocean from 94 passes of short pulse GEOS-3 radar altimeter data received by the DoD telemetry station at Perth, Australia. This data was taken over a 34 day period in July-August 1975. The orbital ephemerides used in the analysis were obtained from Doppler tracking data and have an estimated accuracy of 2 meters in the radial component, reference 7.

This preliminary derivation of the geoid does not consider tide effects on the altimeter measurements which could introduce uncertainties of about 0.5 meters. Also, the standard tropospheric range correction used on the data could result in errors in individual measurements of up to 25 centimeters. A technique for reducing all the biases by analyzing the radar altimeter measurements at track intersections is employed. A later analysis is planned that will include data from other telemetry stations in the area whose coverage overlaps the Perth coverage and extends the total time span of the data set to several months. It will include tidal corrections to the data before the bias removal and geoid derivation is carried out.

The preliminary GEOS-3 geoid derived in the paper is compared with the Marsh and Chang 1976 Geoid, ref. 8. Correlations of larger features in the GEOS-3 geoid with bottom topography are also given.

PROCEDURE

Averaging at Intersections

Ninety-four passes of short pulse radar altimetry data were taken by the Perth, Australia telemetry station and processed at NSWC/DL using precise short-arc Doppler derived satellite ephemerides. For each pass time, latitude, longitude, geoid height and along-track deflections of the vertical were computed at 0.1 second time intervals. Details of this processing, including the Wiener filter used, may be found in reference 9. Nine of the passes contained data too fragmented for efficient operation of the Wiener filter and were eliminated from the following analysis. The remaining 85 passes were used. The ground tracks of these passes are given in Figure 1. The differences in geoid height at each of the 716 intersections of these passes are given in Table 1. The average difference of geoid height over all the intersections is 75 cm with a standard deviation with respect to the mean of 2.3 meters. The maximum difference is 7.83 meters. As a first approximation to the geoid, the average of the two geoid heights at each intersection is taken as the geoid height and contours of constant geoid height plotted. Since along-track deflection of the vertical is available for each track at each intersection, the surface gradient at each intersection may be computed. This is used as an interpolation aid in plotting the geoid height contours. A geoid derived in this manner is given in Figure 2. The +'s in Figure 2 represent the location of the intersections. The contour interval in Figure 2 is 2 m. The General Purpose Contouring Program by California Computer Products was used to generate the contours in Figure 2 and all subsequent contour plots.

Bias Removal

If one studies the intersections in Table 1, it is seen that some passes have all positive differences, e.g. descending pass 1580, or all negative differences. e.g. descending pass 1837. Since pass 1580 is intersected by 19 other passes taken over a time span of 33 days and pass 1837 is intersected by 16 other passes taken over a time span of 32 days, one could assume that different tidal phases, different deviations from the standard troposphere, different orbit uncertainties on the crossing passes would be sampled. Therefore the intersections would be expected to be more random unless the single pass, i.e. 1580 or 1837, was biased with respect to the other passes. Using this assumption each pass in Table 1 has been adjusted so that the sum of the intersection differences with the crossing passes have been minimized. The mean bias adjustment is 0 cm; thus the mean

geoid is not changed. The standard deviation of the biases is 2.2 m. The amount of the adjustment of each pass is given in Table 2. The intersection differences after applying the adjustments are presented in Table 3, where the average difference summed over all intersections is now 9 cm with a standard deivation of 83 cm with respect to the mean and a maximum difference of 3.15 m. The geoid heights are again taken as the midpoint at each intersection and a contour map is made as before using the surface gradient at each intersection to aid in interpolation.

RESULTS

Comparison With the Marsh and Chang 1976 Geoid

The preliminary eastern Indian Ocean geoid derived from the GEOS-3 measurements using the bias removal technique described above is given in Figure 3. The +'s plotted on Figure 3 indicate the locations of the intersections. Figure 4 is a plot of the Marsh and Chang 1976 Geoid. A contour plot of the differences between the GEOS-3 Geoid after bias removal and the Marsh and Chang 1976 Geoid is given in Figure 5. The contour interval in Figures 3,4, and 5 is 2 m. In general the agreement is good, with major features such as the through running from the southwestern tip of Australia toward the northwest, and the saddle point south of Australia comparing well. The maximum difference between the two geoids is 7 m. To further compare the two geoids, the along-track geoid heights (after bias removal) from pass 1419 and descending pass 1724 are compared in Figures 6 and 7, with the Marsh and Chang 1976 geoid heights along these tracks. Again the agreement is quite good, with the GEOS-3 along-track data showing more fine structure than was apparent in the overall geoid plots, since the GEOS-3 contour plots used information only at the intersections instead of at every point along-track. Both the GEOS-3 Geoids and the Marsh and Chang 1976 Geoid were referenced to an ellipsoid with a semi-major axis of 6378.135 km and a flattening reciprocal of 298.26.

Comparison with Bottom Topography

Comparison of the GEOS-3 Geoid was made with larger bottom topography features of the eastern Indian Ocean. Figure 8 is a contour map of a small area of the geoid with a one meter interval between contour lines. Figure 9 is a three dimensional projection of the same area shown in Figure 8. Comparison of Figures 3, 8 and 9 with ocean bottom charts shows good agreement with large features. An attempt was made to correlate the GEOS-3 Geoid with finer scale bottom topographic features

shown on a detailed charts supplied by the Naval Oceanographic Office without much success, probably due to the smoothing of the GEOS-3 Geoid by using data only at intersections in its construction. Much success was had by making along-track comparisons where the short wavelength information is not lost. Figure 10 shows an along-track comparison of bottom topography and geoid heights for pass 1746. Geoid heights are plotted for the GEOS-3 Geoid after bias removal as well as the along-track satellite data. The lack of short wavelength information in the GEOS-3 Geoid is evident. Correlation of the three curves is very good. The sea mount near the middle of the pass shows up clearly in the two geoid height curves. The sea mount is located approximately at lattitude -22°2 and longitude 104°6. The geoid undulations caused by this sea mount can be seen in figures 2,3,4,8, and 9.

CONCLUSIONS

Careful processing of GEOS-3 radar altimetry data with good orbit ephemerides can result in a derived ocean geoid that is accurate to about one meter. It is expected that greater accuracy will be obtained in the GEOS-3 Geoid with the analysis of additional data in the area from other telemetry stations whose coverage partially overlaps Perth and which will provide data over a longer time frame. Also the inclusion of tide and sea state corrections and a bias rate term in the analysis should result in greater accuracy in the derived geoid. The use of along-track data (instead of using only intersection data) should improve the accuracy and the short wavelength structure of the GEOS-3 Geoid.

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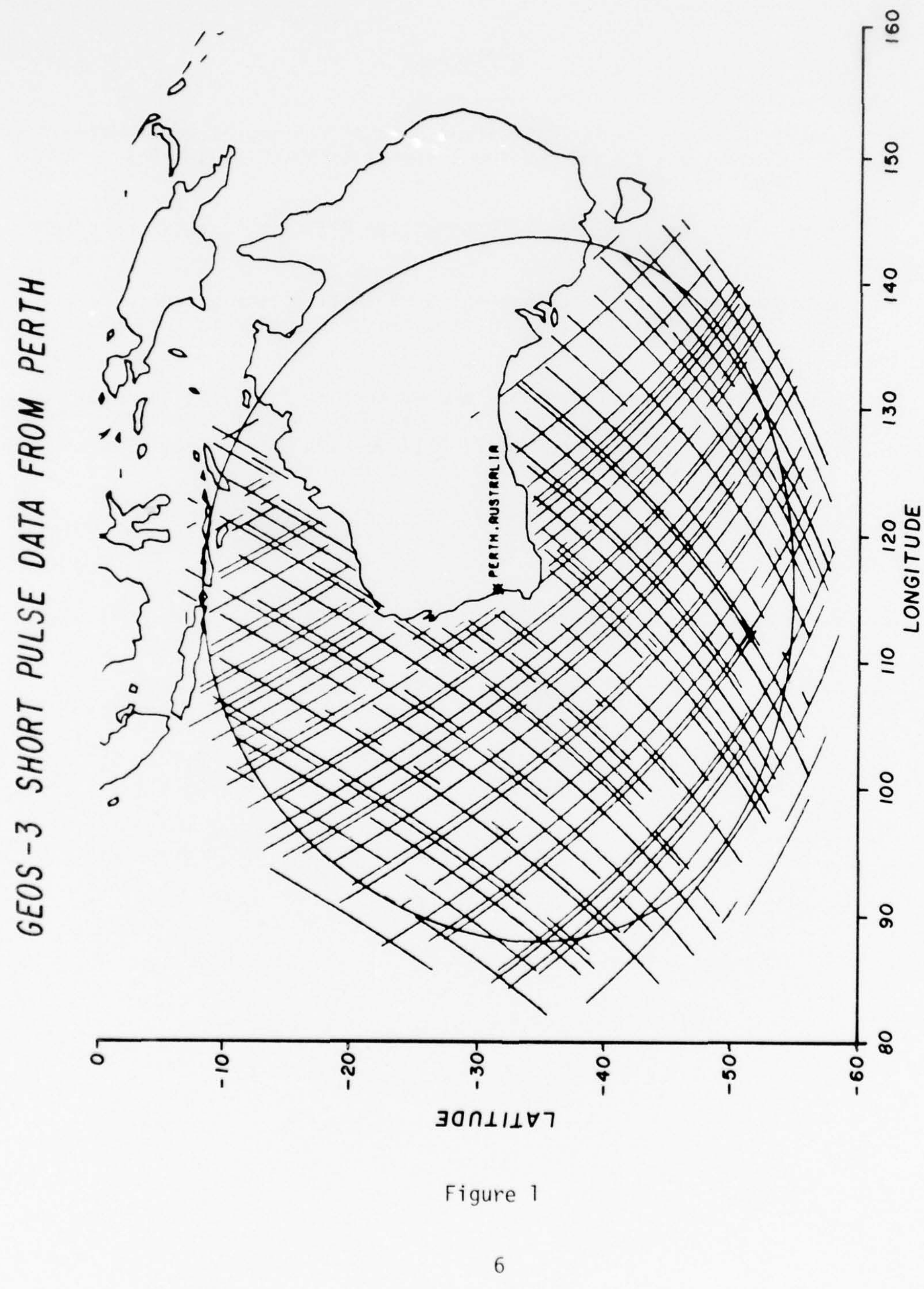
GEOS-3 SHORT PULSE DATA FROM PERTH
PERTH, AUSTRALIA
LATITUDE
0
-10
-20
-30
-40
-50
-60
LONGITUDE
80
90
100
110
120
130
140
150
160

Figure 1

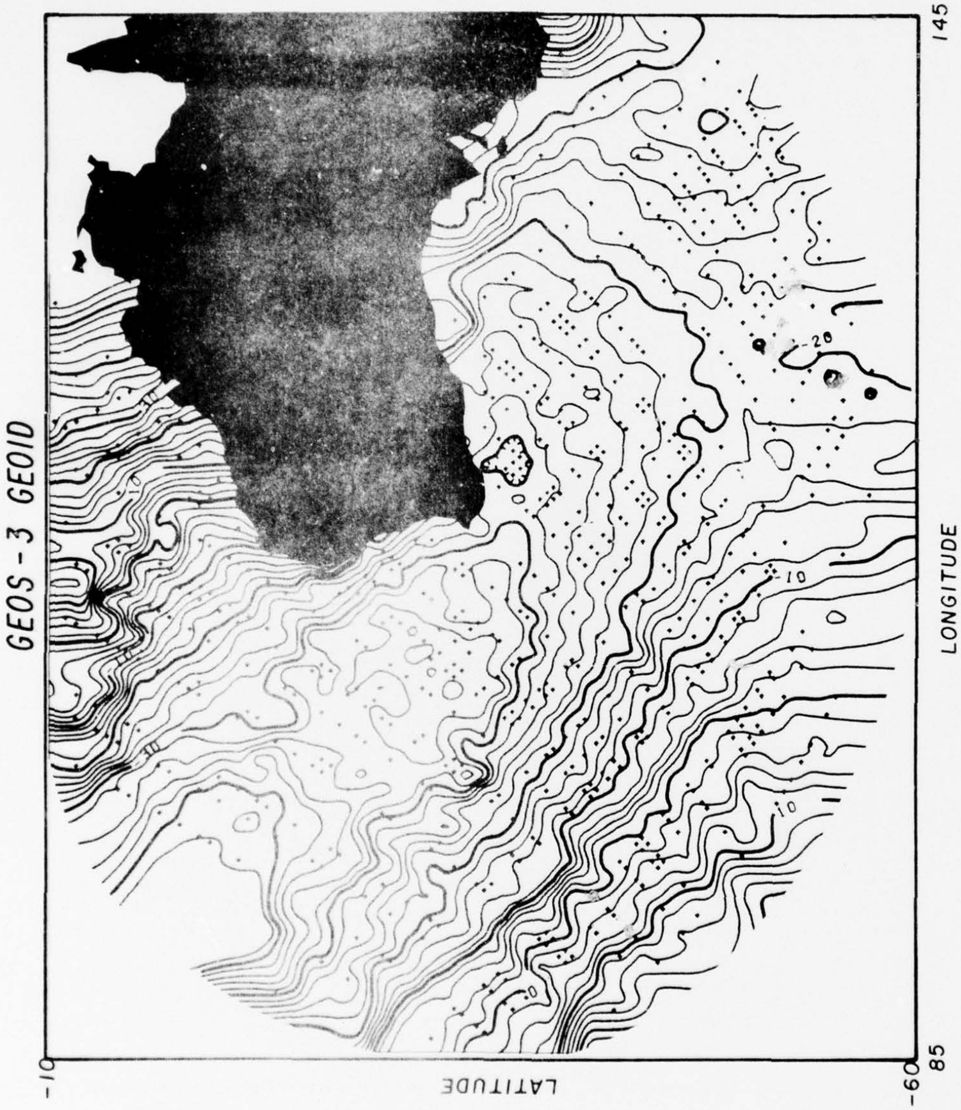

Figure 2


GEOS-3 GEOID AFTER BIAS REMOVAL
LATITUDE
LONGITUDE
-10
-60
85
145
-10
-40
0
20
-10
0

Figure 3

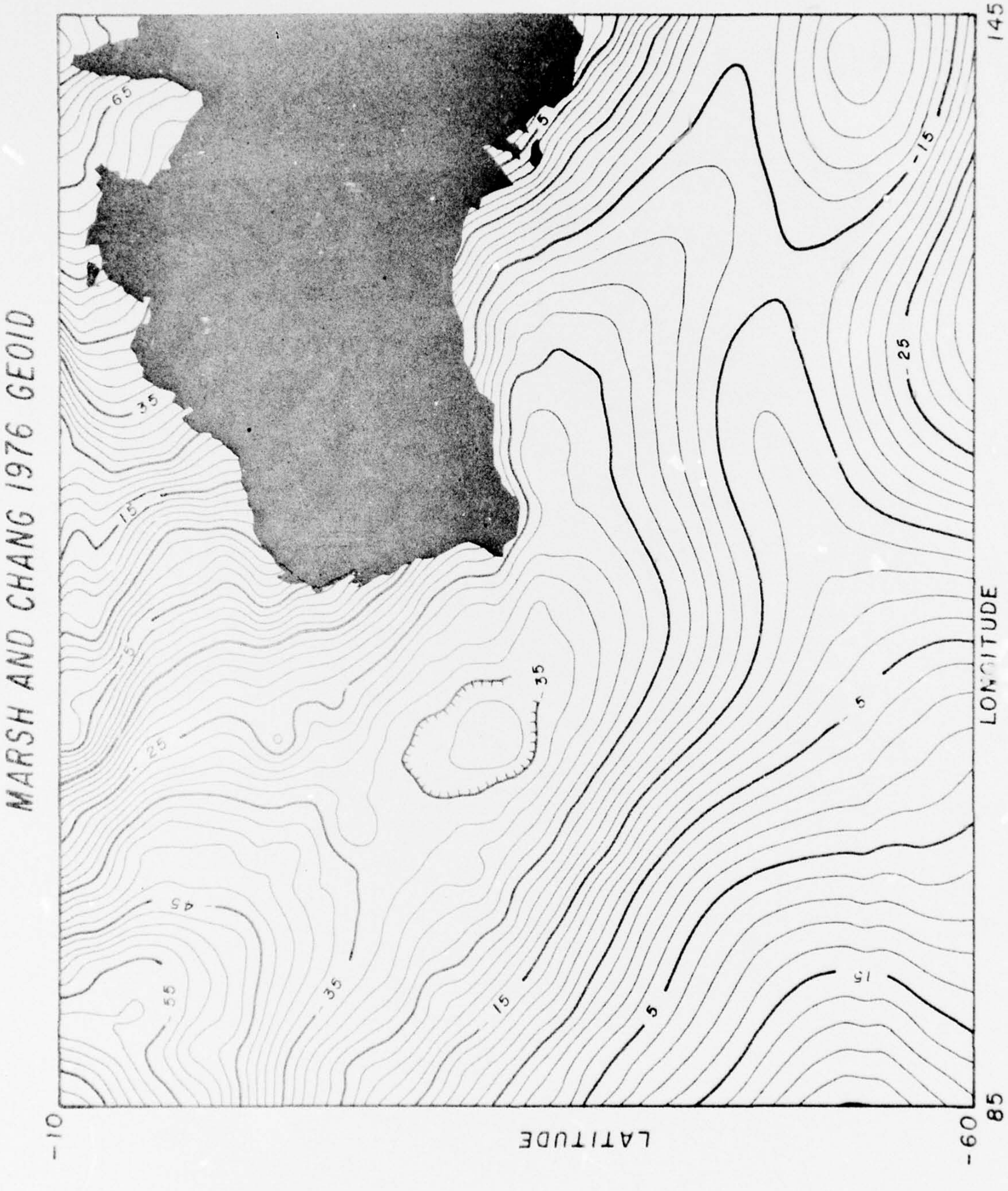

Figure 4

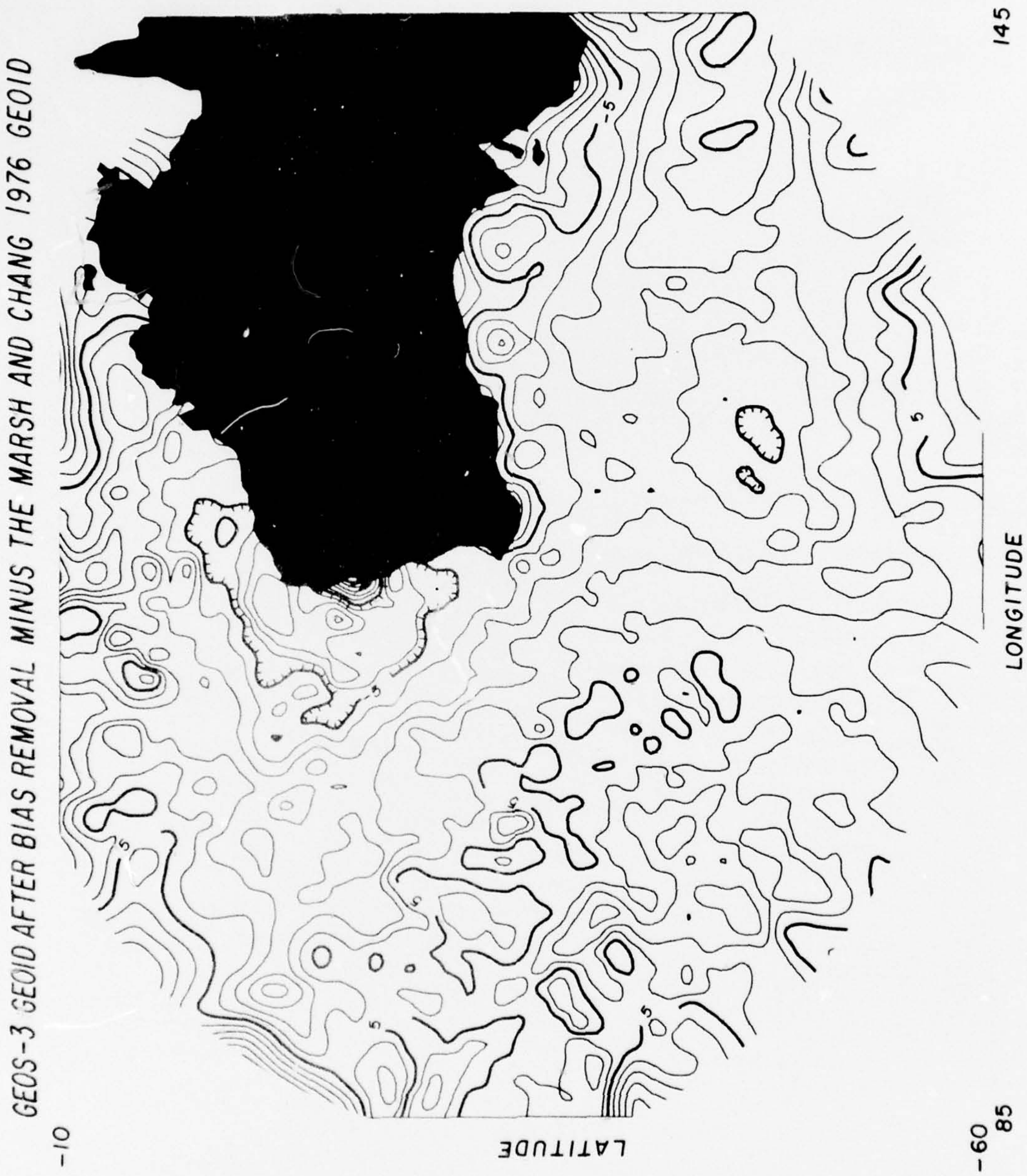
GEOS-3 GEOID AFTER BIAS REMOVAL MINUS THE MARSH AND CHANG 1976 GEOID
LATITUDE
LONGITUDE
-10
-60
85
145
-5
5

Figure 5

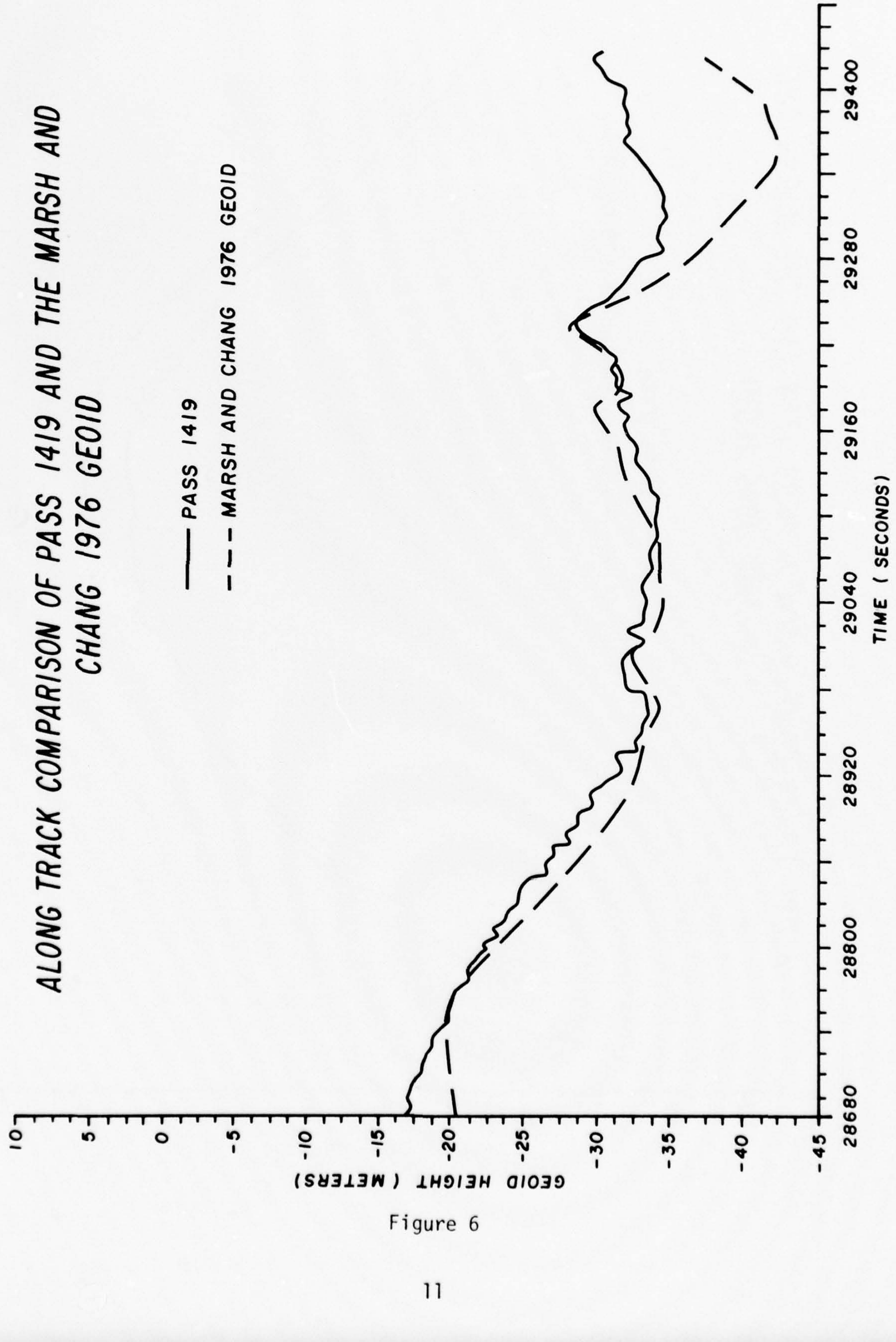
ALONG TRACK COMPARISON OF PASS 1419 AND THE MARSH AND CHANG 1976 GEOID
PASS 1419
MARSH AND CHANG 1976 GEOID
GEOID HEIGHT (METERS)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
TIME (SECONDS)
28680
28800
28920
29040
29160
29280
29400

Figure 6

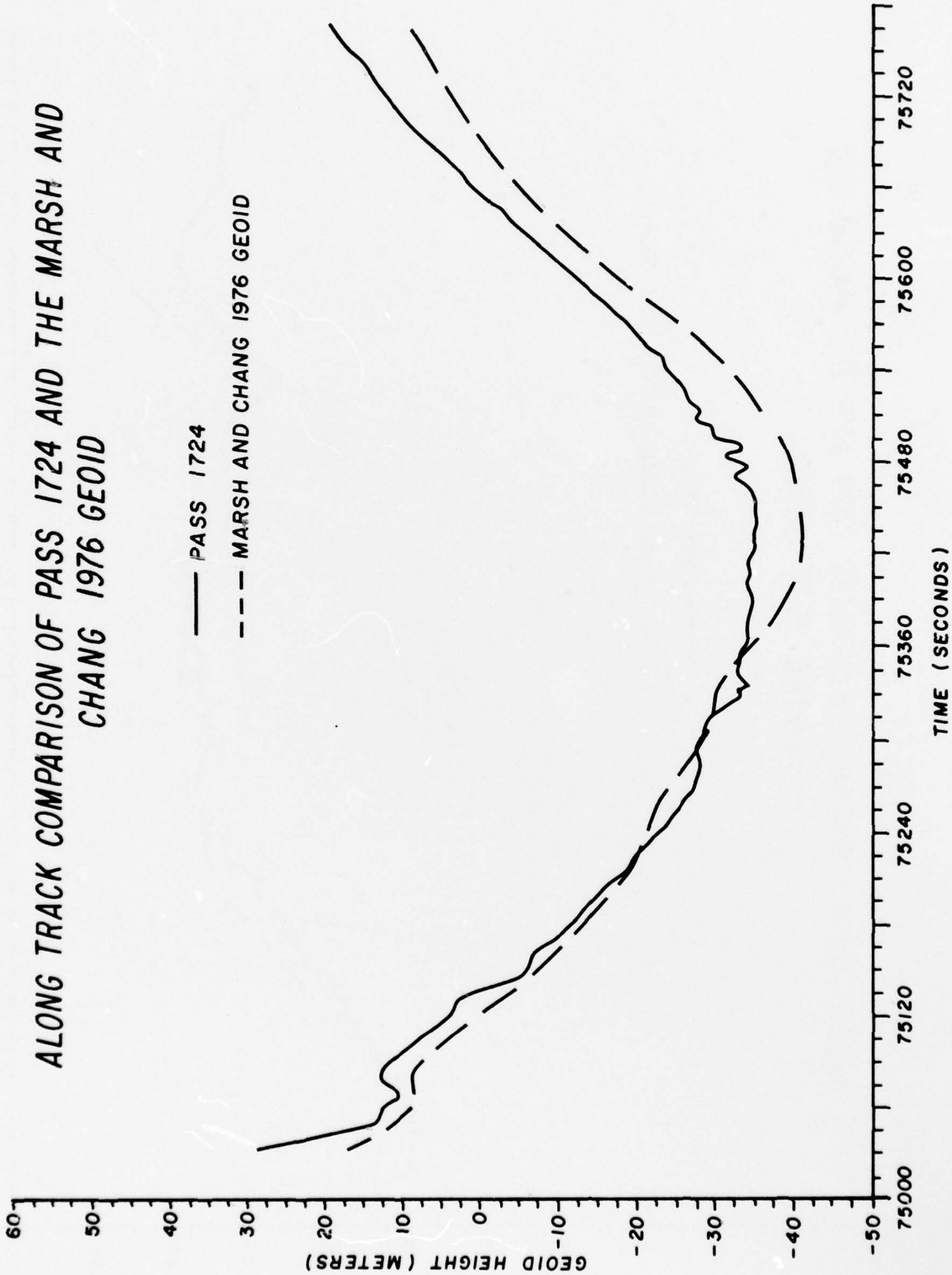
ALONG TRACK COMPARISON OF PASS 1724 AND THE MARSH AND CHANG 1976 GEOID
PASS 1724
MARSH AND CHANG 1976 GEOID
GEOID HEIGHT (METERS)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
TIME (SECONDS)
75000
75120
75240
75360
75480
75600
75720

Figure 7

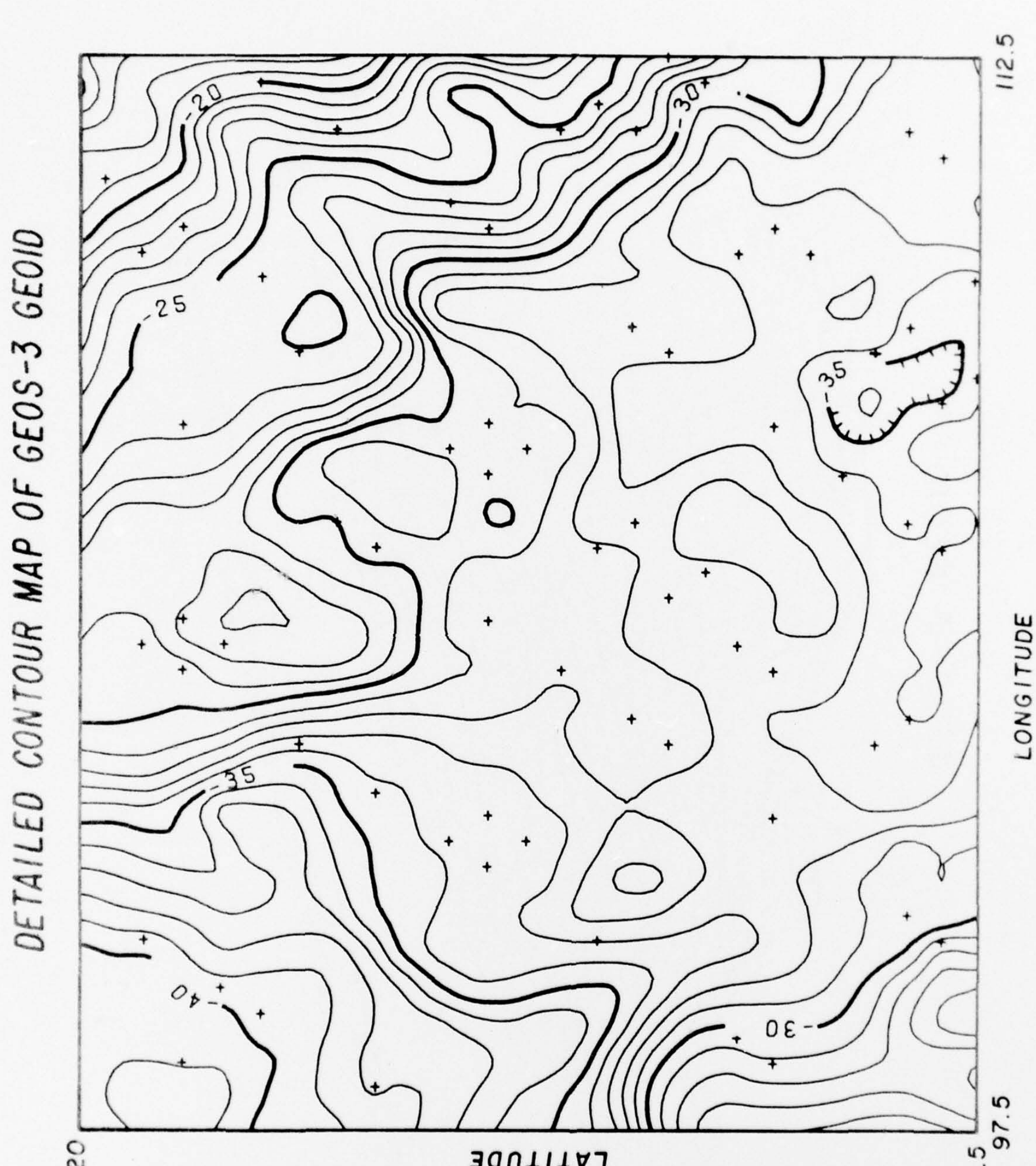
DETAILED CONTOUR MAP OF GEOS-3 GEOID
LONGITUDE
LATITUDE
-20
-32.5
97.5
112.5
-20
-25
-30
-35
-35
-40
-30

Figure 8

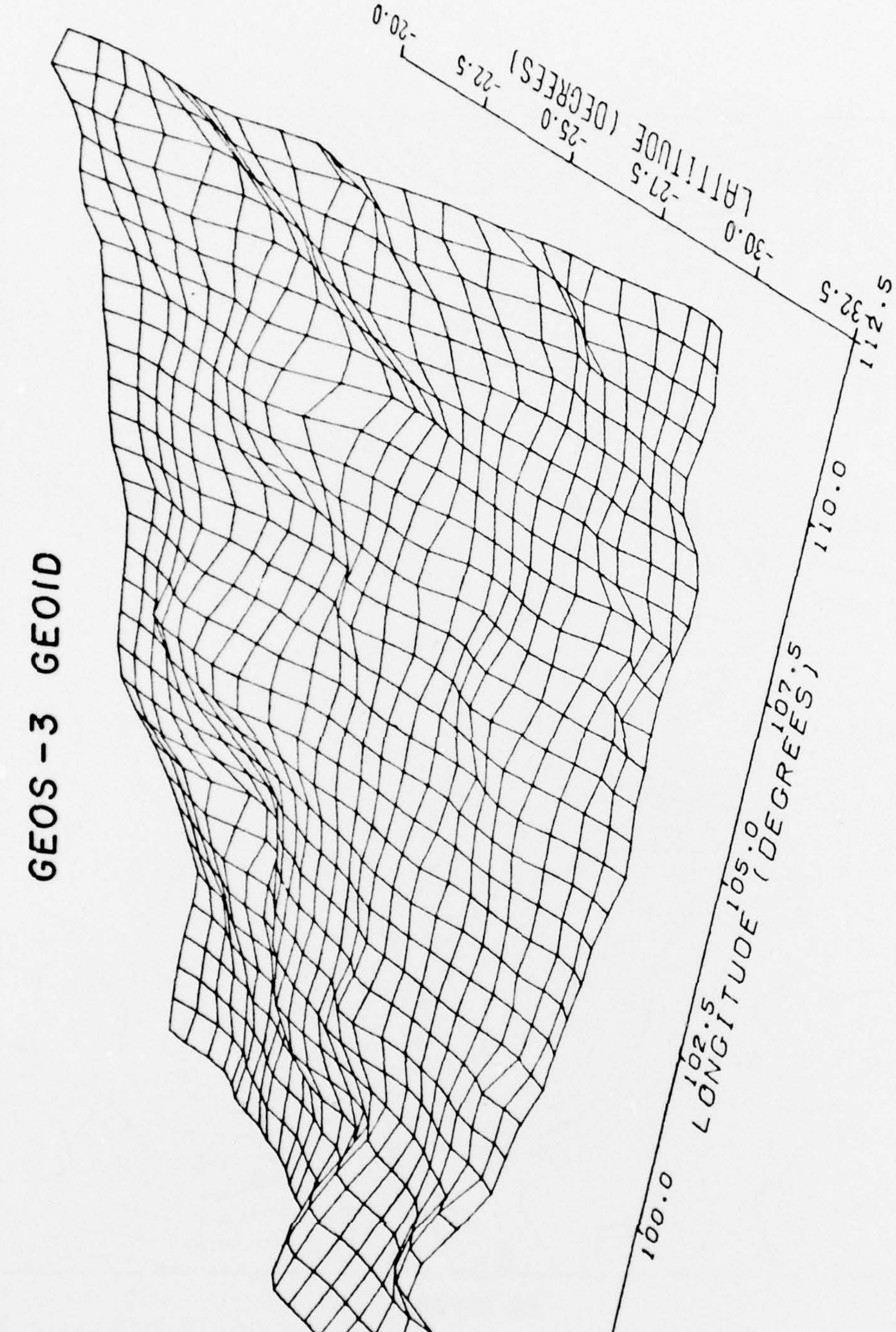
GEOS-3 GEOID
LATITUDE (DEGREES)
-20.0
-22.5
-25.0
-27.5
-30.0
-32.5
LONGITUDE (DEGREES)
97.5
100.0
102.5
105.0
107.5
110.0
112.5
GEOID HEIGHT (M)
-42
-35
-28
-21
-14

Figure 9

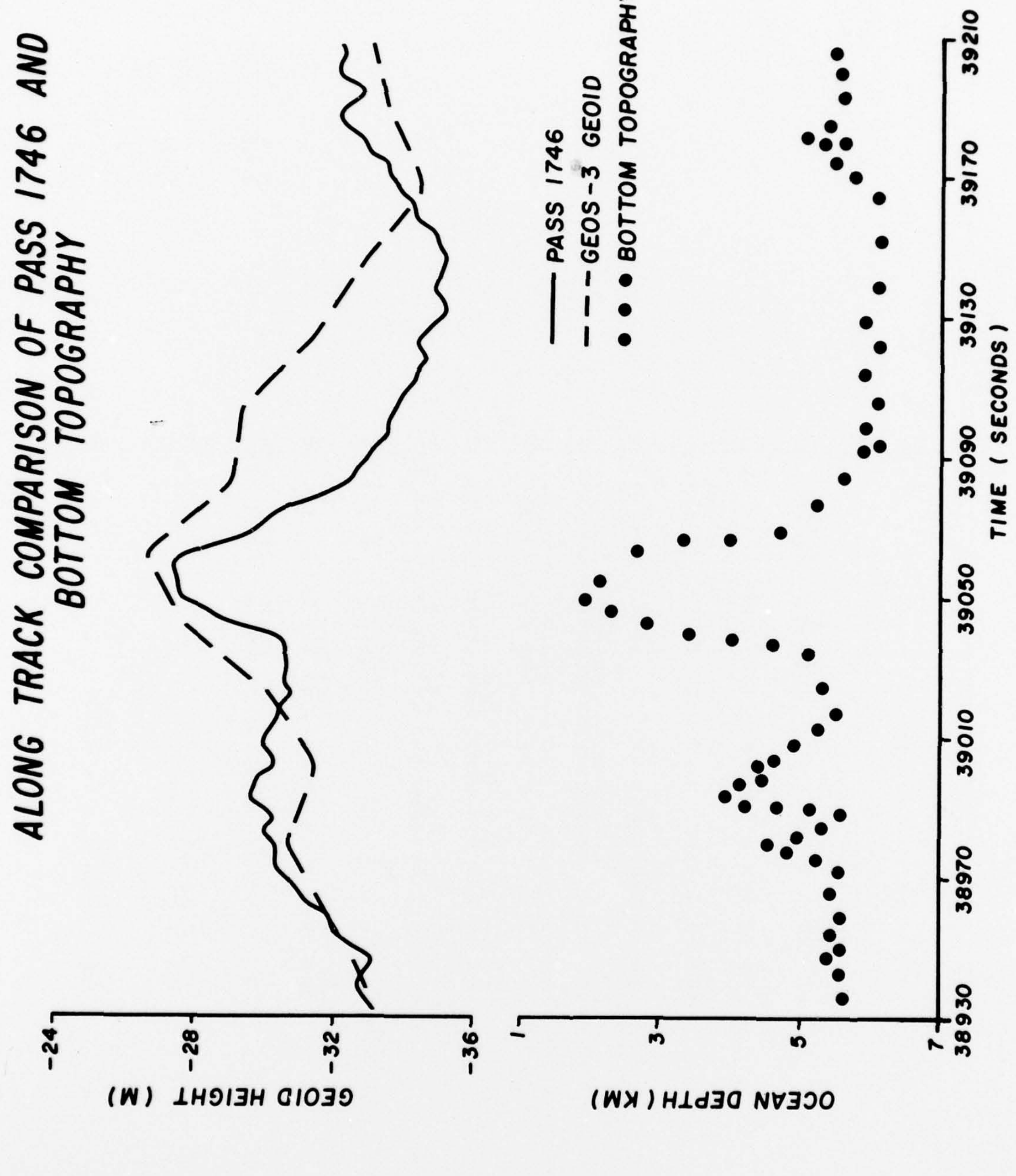
ALONG TRACK COMPARISON OF PASS 1746 AND
BOTTOM TOPOGRAPHY
GEOID HEIGHT (M)
-24
-28
-32
-36
PASS 1746
GEOS-3 GEOID
BOTTOM TOPOGRAPHY
OCEAN DEPTH (KM)
1
3
5
7
38930
38970
39010
39050
39090
39130
39170
39210
TIME (SECONDS)

Figure 10

TABLE 1

GEOID HEIGHT DIFFERENCES AT INTERSECTIONS (METERS)

D E S C E D N I N G P A S S E S

Descending Passes / Ascending Passes	1354	1368	1382	1383	1396	1397	1410	1411	1424	1425	1426	1566	1568	1580	1581	1624	1637	1651	1652	1653	1665	1666	1667	1680	16
1347																									2.
1349				1.97				3.22			2.76		2.61		.28	1.02				2.92			2.33		2.
1362	.70		-2.14	1.42				1.84		-.10			2.43	3.25	-.93			2.18	-.71		.66		1.85	2.83	1.
1376					.70	2.88	2.61							4.17			4.99	3.70	.86	3.67	1.92	2.35	3.16	4.60	
1390					-.33	-.42	1.36	.36	2.26					2.87			3.50	2.49		.86	.35	.60	.62	3.15	
1391	-2.14	-4.90			-2.78	-1.04		-.96		-3.45			-1.43			-3.38			-3.18	-1.10		-2.17	-1.48	-.15	-1.
1404	-4.99						.57	-2.21	2.30					2.48			3.35	2.19			.67		-1.99	2.35	-.
1405	-1.18	-4.05		-1.34	-1.82		.08	-.61			-1.42		-1.27		-2.48	-2.41			-2.06	-.44			-1.05	1.52	
1406								3.90								1.93				3.15			3.13		
1418																									-1.1
1419			-4.29	-.92	-2.00	.32	.28	-.35		-2.45	-.15				-2.33	-1.83	2.59		-2.15	.31		-.69	-.24	1.66	.
1420		.12		2.69				3.81			3.16		2.94		.87	1.71			.63				3.52		3.3
1433					.86	3.26	3.01	2.59					3.69	4.72	.09		5.32	4.19		4.18	2.23	2.17	3.08	4.73	
1434		-.17		2.63	1.55		2.49	3.70		.36	3.72		3.50		.70	1.64			.50	3.82		1.59	2.58		3.1
1447					.62	1.11	2.87		3.73					3.81			4.77	3.62		2.10	1.72	1.73	1.65	4.49	
1561	1.76				.74	3.26									-.43			3.32			2.04	1.65		4.56	
1575					2.12	2.56	4.15							5.59			5.77	4.75		3.41	3.39	3.48	2.80	5.62	
1633		-2.58			-.96		.66	1.74		-1.05	1.37		1.70	2.80	-1.69	-.97	3.05	1.89	-1.41	1.65	.50	-.25	1.14	2.49	.
1646						1.43														2.18			1.94		
1647																		.57			-.15				
1660																							-1.33		.
1661	-1.36	-3.41			-1.49	.66	.49	-.01			.02		.14	2.40	-2.21	-1.91	3.17		-1.88	.41		-.68	-.04	1.13	.
1662															.21	.87			-.01			.85	2.26		
1674	-6.19							-3.34																	-2.3
1675	-2.30	-4.39			-2.09	-1.08	-.52	-1.05			-1.45		-.89	1.28	-3.31	-2.79	1.85	.72	-2.49	-.43		-.90	-1.02	.58	-1.3
1676				1.95				2.35			1.96		2.02		-.06	.37			.26	2.18		.99	2.36		
1689	-.37		-2.95		-1.13		1.04	.97		-.56	1.27		1.37		-2.02	-1.49	2.95	2.11	-1.25	1.89	.17	.43	.54	2.45	.
1703					1.57	2.37	2.92							4.64			5.58	3.77	.73	3.18	2.63	2.65	2.58	4.50	
1704	.96	-1.70			-.25			2.66		-.56	3.29	3.08	2.80	2.51	-1.08		3.19	1.98	-.95	2.93		.37	2.14		1.2
1717						-1.41		-.74												-.27			-.61		
1718	-.56	-3.10			-1.39	.79	.37	1.50					1.27	2.23	-2.15	-1.58	2.54	1.52	-1.71	.99	.23	-.54	.64	1.29	.
1731	-7.83							-3.50															-3.57		-2.8
1732	-2.00	-4.39		-1.79	-2.32		-1.04	-.68			-1.33		-1.23	1.85	-3.37	-2.80	1.50		-3.11	-.38	-.07	-1.56	-1.31	.07	
1745														2.84											
1746			-3.85	-.15	-1.50	.62	.07	.41		-2.13	.29			1.93	-2.37	-2.14	2.10		-2.08	.89	-.62	-.44	.15		-.1
1747		.11		3.66				4.35			4.00		3.68	5.18	.92	2.19			1.01			2.00	4.24		3.6
1759																-2.96									
1775	1.38	-1.61		2.03	.05	2.97	.78	2.55					2.77		-.53	.07			-.51			-.09	1.98	2.28	2.0
1803	-1.00	-3.24			-1.18	.46	.34	-.24			-.72		-.20	2.42	-2.21	-1.59	2.77	1.91	-1.69	.39	.34	-.43	.17	1.84	.1
1831					.85	2.97	2.49						3.55	2.72	-.08		4.76	3.44	.36	3.73	2.14	1.93	2.87	3.84	

2

TABLE I

HEIGHT DIFFERENCES AT INTERSECTIONS (METERS)

D E S C E N D I N G   P A S S E S

51	1652	1653	1665	1666	1667	1680	1681	1682	1694	1696	1708	1709	1710	1722	1723	1724	1736	1737	1738	1739	1752	1809	1837
							2.70												2.00				
		2.92			2.33		2.90			1.24		-.99	1.46			3.58			2.68				-1.90
18	-.71		.66		1.85	2.83	1.96			1.37	2.84	-1.96	2.44	1.52	-.74		1.06		1.99			2.18	
70	.86	3.67	1.92	2.35	3.16	4.60			4.14		3.78		3.65	2.23	.55	4.94	2.74	2.82					
49		.86	.35	.60	.62	3.15			3.02		2.13			1.29		2.55	1.86	1.15	.97			-.13	
	-3.18	-1.10		-2.17	-1.48	-.15	-1.49		.49	-3.07		-5.08	-2.11		-3.47	-.54			-1.21			-1.53	-6.57
19			.67		-1.99	2.85	-.83		2.75		2.53			.69			1.22		-1.23			-2.34	
	-2.06	-.44			-1.05	1.52			2.28			-4.20	-1.15		-1.75	.14		.56	-.61			-.48	-5.16
		3.15			3.13											3.19							
							-1.10														-3.89		
	-2.15	.31		-.69	-.24	1.66	.08		1.94	-.94		-4.15	.06		-2.20	1.52		.39	.15				-5.77
	.63				3.52		3.30			1.98		-.73	1.85		.98	4.01			3.19				-1.74
19		4.18	2.23	2.17	3.08	4.73			5.03	2.79	4.61		3.73	3.46	.64	5.08	3.03	3.57					
	.50	3.82		1.59	2.58		3.12			2.13		-1.03	2.35		.53	3.58		2.25	2.87			2.86	-2.09
62		2.10	1.72	1.73	1.65	4.49			4.34		4.23		1.91	2.58	.37	3.71	2.46	2.89	2.06				
32			2.04	1.65		4.56			4.41	1.95			2.55	2.77			2.07						
75		3.41	3.39	3.48	2.80	5.62			6.07		4.77		3.24	4.60	1.19	4.59	3.55	3.98	3.32				
89	-1.41	1.65	.50	-.25	1.14	2.49	.97	1.15	2.16	-.29	1.67	-3.23	.77		-.45	2.37		.49	1.45			.93	-4.21
		2.18			1.94								2.26			3.78							
57			-.15											.35									
					-1.33		.27									.59			-.41			-1.74	
	-1.88	.41		-.68	-.04	1.13	.06		1.83	-1.60	2.24	-3.54	-.74	1.19	-1.93	1.31		.01	.36			.35	-5.03
	-.01			.85	2.26							-1.29	1.24		-.24	2.57		1.56	2.06				-2.07
							-2.38												-2.59			-3.55	
72	-2.49	-.43		-.90	-1.02	.58	-1.37		1.12	-1.82	1.06	-4.63	-1.25	.12	-3.02	.32		-.72	-.84			-1.07	-6.55
	.26	2.18		.99	2.36					.72		-1.21	.81		.02	2.96		2.10	2.34				-2.43
11	-1.25	1.89	.17	.43	.54	2.45	.84		2.04	.83		-3.08	1.49	.82	-1.45	2.59		1.51				1.10	-5.38
77	.73	3.18	2.63	2.65	2.58	4.50			4.83		4.60		3.16	2.92	1.01	4.31	3.21	3.44					
98	-.95	2.93		.37	2.14		1.21	3.01	2.40	1.60	2.86	-2.69	1.97		-1.06	3.21		.74	2.18	2.59		1.52	
		-.27			-.61											1.38			-.18				
52	-1.71	.99	.23	-.54	.64	1.29	.44		1.90	-.29	1.65	-3.72	.37	.55	-1.44	1.81		.20	.76			.26	
					-3.57		-2.84												-2.87			-3.92	
	-3.11	-.38	-.07	-1.56	-1.31	.07			.93	-2.21	1.21	-4.69	-1.50	.40	-2.70	.09	.67	-.60	-.57				-5.99
	-2.08	.89	-.62	-.44	.15		-.17		1.62	-.76	1.63	-4.16	.04	.67	-2.31	1.40	.62	.09					-5.26
	1.01			2.00	4.24		3.63	3.61	4.30	2.40		-.74	2.56		1.20	4.18		2.92	3.75				-1.25
	-.51			-.09	1.98	2.28	2.05			1.02		-1.97	1.60		-.96	2.91		.95	2.25			1.92	
91	-1.69	.39	.34	-.43	.17	1.84	.17		1.83	-1.61	2.12	-3.84	-.26	1.42	-1.37	1.03	.81	.47	.10			-.11	-5.03
44	.36	3.73	2.14	1.93	2.87	3.84			4.24		3.95		3.10	2.51	.56	4.63	2.48	2.48					

TABLE 2

BIASES (METERS)

Ascending Passes

Pass No.	Bias
1347	2.0255
1349	1.4120
1362	.8006
1376	2.6962
1390	1.1268
1391	-2.6197
1404	.1451
1405	-1.5824
1406	2.7338
1418	-2.8210
1419	-1.1408
1420	1.5730
1433	2.9797
1434	1.5557
1447	2.3771
1561	2.0308
1575	3.6217
1633	.1213
1646	1.9914
1647	-.0689
1660	-.8489
1661	-.6609
1662	.3416
1674	-3.9360
1675	-1.5822
1676	.7676
1689	-.0942
1703	2.9032
1704	1.0856
1717	-.6313
1718	-.1651
1731	-4.4150
1732	-1.6223
1745	2.5125
1746	-.8584
1747	2.3044
1759	-3.2807
1775	.7127
1803	-.5055
1831	2.3792

Descending Passes

Pass No.	Bias
1354	2.0087
1368	2.8957
1382	3.6436
1383	-.7709
1396	.7984
1397	-.8719
1410	-.9172
1411	-.5216
1424	-2.4272
1425	1.5748
1426	-.7826
1566	-2.7478
1568	-1.2155
1580	-2.8077
1581	1.4333
1624	1.1353
1637	-3.2068
1651	-2.2751
1652	1.2811
1653	-1.3553
1665	-.7464
1666	-.2933
1667	-.7286
1680	-2.3492
1681	-.2807
1682	-2.2569
1694	-2.5601
1696	.0629
1708	-2.4820
1709	3.1803
1710	-.9380
1722	-1.3373
1723	1.0554
1724	-2.2592
1736	-1.6476
1737	-1.1118
1738	-.5532
1739	-2.2550
1752	4.2271
1809	.5532
1837	4.4850

TABLE 3

GEOID HEIGHT DIFFERENCES AT INTERSECTIONS AFTER BIAS REMOVAL

Ascending Passes

Descending Passes	1354	1368	1382	1383	1396	1397	1410	1411	1424	1425	1426	1566	1568	1580	1581	1624	1637	1651	1652	1653	1665	1666	1667
1347																							
1349				-.21				1.29			.56		-.01		.30	.75				.15			.19
1362	1.91		.70	-.15				.52		.67			.41	-.36	-.30			-.89	-.23		-.89		.32
1376					-1.20	-.68	-1.00							-1.34			-.91	-1.27	-.56	-.39	-1.52	-.64	-.27
1390					-.66	-2.42	-.68	-1.29	-1.30					-1.06			-.83	-.91		-1.63	-1.52	-.82	-1.23
1391	2.49	.62			.64	.70		1.14		.75			-.03			.37			.72	.16		.16	.41
1404	-3.13						-.50	-2.88	-.27					-.47			-.01	-.23			-.22		-2.86
1405	2.41	.43		-.53	.57		.74	.45			-.62		-.90		.54	.31			.80	-.21			-.20
1406								.65								.33				.94			-.34
1418																							
1419			.49	-.55	-.06	.59	.50	.27		.26	.20				.24	.45	.52		.27	.10		.15	.17
1420		1.44		.35				.172			.80		.15		.73	1.27			.33				1.22
1433					-1.32	-.60	-.89	-.92					-.51	-1.07	-1.45		-.87	-1.06		-.16	-1.49	-1.10	-.63
1434		1.17		.31	.79		.01	1.62		.38	1.38		.73		.57	1.22			.22	.91		-.26	.29
1447					-.96	-2.14	-.42		-1.08					-1.38			-.82	-1.03		-1.63	-1.41	-.94	-1.46
1561	1.73				-.50	.36									-1.02			-.99			.74	-.67	
1575					-.71	-1.93	-.38							-.84			-1.06	-1.15		-1.56	-.98	-.43	-1.55
1633		.20			-.29		-.38	1.10		.41	.46		.37	-.13	-.38	.05	-.28	-.50	-.25	.17	-.36	-.67	.29
1646						-1.43														-1.17			-.78
1647																		-1.63			-.83		
1660																							-1.21
1661	1.31	.15			-.03	.45	.23	.13			-.10		-.42	.26	-.12	-.12	.63		.06	-.28		-.31	-.11
1662															1.30	1.67			.93			.21	1.19
1674	-.25							.07															
1675	1.29	.09			.29	-.37	.14	.01			-.65		-.52	.06	-.30	-.07	.22	.02	.38	-.20		.39	-.16
1676				.42				1.06			.41		.04		.60	.74			.77	.06		-.07	.86
1689	1.73		.79		-.24		.22	.54		1.11	.58		.25		-.49	-.26	-.16	-.07	.12	.63	-.48	.24	-.09
1703					-.54	-1.40	-.90							-1.07			-.53	-1.41	-.39	-1.08	-1.01	-.55	-1.05
1704	1.89	.11			-.54			1.05		-.07	1.42	-.75	.50	-1.38	-.73		-1.10	-1.38	-.75	.49		-1.01	.33
1717						-1.65		-.63												-1.00			-.71
1718	1.61	-.04			-.43	.09	-.38	1.14					.22	-.41	-.55	-.28	-.50	-.59	-.27	-.20	-.35	-.67	.07
1731	-1.41							.39															.11
1732	1.63	.12		-.94	.10		-.34	.42			-.49		-.83	.67	-.32	-.04	-.08		-.21	-.11	.81	-.23	-.41
1745														-2.48									
1746			.65	-.06	.16	.60	.01	.74		.31	.37			-.02	-.07	-.15	-.25		.06	.39	-.51	.12	.28
1747		.70		.58				1.52			.91		.16	.07	.05	1.02			-.01			-.60	1.20
1759																1.46							
1775	2.67	.57		.54	.14	1.38	-.85	1.32					.84		.19	.50			.06			-1.10	.54
1803	1.51	.17			.12	.09	-.07	-.26			-1.00		-.91	.12	-.27	.05	.07	.14	.10	-.46	.30	-.22	-.05
1831					-.73	-.28	-.80						-.05	-2.47	-1.03		-.83	-1.21	-.73	-.00	-.98	-.74	-.24

2

TABLE 3

D HEIGHT DIFFERENCES AT INTERSECTIONS AFTER BIAS REMOVAL (METERS)

1637	1651	1652	1653	1665	1666	1667	1680	1681	1682	1694	1696	1708	1709	1710	1722	1723	1724	1736	1737	1738	1739	1752	1809	1837
								.39												-.57				
			.15			.19		1.20			-.11		.78	-.89			-.09			.72				1.18
	-.89	-.23		-.89		.32	-.32	.88			.63	-.45	.42	.70	-.62	-.49		-1.39		.64			1.94	
-.91	-1.27	-.56	-.39	-1.52	-.64	-.27	-.44			-1.12		-1.40		.02	-1.80	-1.89	-.01	-1.61	-.99					
-.83	-.91		-1.63	-1.52	-.82	-1.23	-.33			-.66		-1.48			-1.17		-.84	-.91	-1.09	-.71			-.70	
		.72	.16		.16	.41	.12	.85		.54	-.39		.72	-.43		.21	-.18			.86			1.64	.53
-.01	-.23			-.22		-2.86	.36	-1.25		.05		-.10			-.79			-.58		-1.93			-1.94	
		.80	-.21			-.20	.76			1.30			.56	-.51		.89	-.54		1.03	.42			1.66	.91
			.94			-.34											-1.80							
								1.44														3.15		
.52		.27	.10		.15	.17	.45	.94		.52	.26		.17	.26		-.00	.40		.42	.73				-.14
		.33				1.22		1.45			.47		.87	-.66		.46	.18			1.06				1.18
-.87	-1.06		-.16	-1.49	-1.10	-.63	-.59			-.51	-.13	-.85		-.18	-.86	-1.28	-.16	-1.60	-.52					
		.22	.91		-.26	.29		1.28			.64		.59	-.14		.03	-.23		-.42	.76			1.85	.84
-.82	[illegible]		-1.63	-1.41	-.94	-1.46	-.23			-.59		-.63		-1.41	-1.13	-.95	-.92	-1.56	-.60	-.87				
	-.99			.74	-.67		.18			-.18	-.02			-.42	-.60			-1.61						
1.06	-1.15		-1.56	-.98	-.43	-1.55	-.35			-.11		-1.33		-1.32	-.36	-1.38	-1.29	-1.72	-.75	-.86				
-.28	-.50	-.25	.17	-.36	-.67	.29	.02	.57	-1.23	-.52	-.34	-.94	-.17	-.29		.48	-.01		-.74	.77			1.36	.15
			-1.17			-.78								-.67			-.47							
	-1.63			-.83											-.92									
						-1.21		.84									-.82			-.12			-.33	
.63		.06	-.28		-.31	-.11	-.56	.44		-.07	-.88	.42	.30	-1.02	.52	-.21	-.28		-.44	.47			1.57	.12
		.93			.21	1.19							1.54	-.04		.47	-.03		.11	1.16				2.07
								1.27												.80			.94	
.22	.02	.38	-.20		.39	-.16	-.19	-.07		.14	-.18	.16	.13	-.60	.36	-.38	-.36		-.25	.18			1.06	-.48
		.77	.06		-.07	.86					.02		1.20	-.90		.30	-.06		.22	1.02				1.23
-.16	-.07	.12	.63	-.48	.24	-.09	.19	.66		-.43	.99		.19	.65	-.43	-.30	.42		.50				1.75	-.80
-.53	-1.41	-.39	-1.08	-1.01	-.55	-1.05	-.76			-.64		-.78		-.68	-1.32	-.84	-.85	-1.34	-.57					
1.10	-1.38	-.75	.49		-1.01	.33		-.15	-.33	-1.24	.58	-.71	-.59	-.06		-1.09	-.13		-1.46	.54	-.75		.99	
			-1.00			-.71											-.24			-.10				
-.50	-.59	-.27	-.20	-.35	-.67	.07	-.90	.32		-.50	-.06	-.66	-.37	-.40	-.62	-.22	-.28		-.75	.37			.98	
						.11		1.30												.99			1.05	
-.08		-.21	-.11	.81	-.23	-.41	-.65			-.00	-.53	.35	.12	-.81	.69	-.02	-.54	.64	-.09	.50				.12
-.25		.06	.39	-.51	.12	.28		.40		-.08	.16	.00	-.12	-.04	.19	-.40	.00	-.17	-.17					.08
		-.01			-.60	1.20		1.05	-.95	-.56	.15		.14	-.68		-.05	-.39		-.50	.89				.93
		.06			-1.10	.54	-.78	1.05			.37		.50	-.05		-.62	-.06		-.86	.98			1.76	
.07	.14	.10	-.46	.30	-.22	-.05	-.00	.40		-.23	-1.04	.15	-.15	-.69	.59	.19	-.73	-.34	-.13	.05			.95	-.04
-.83	-1.21	-.73	-.00	-.98	-.74	-.24	-.89			-.70		-.92		-.21	-1.21	-.76	-.01	-1.54	-1.01					

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*) Ninety-four passes of GEOS-3 short pulse radar altimetry data taken in July-August 1975 over the eastern Indian Ocean (by the DoD telemetry station at Perth, Australia) have been analyzed to arrive at a preliminary ocean geoid. The self consistency of the data at track intersections has a mean geoid height difference of 75 cm with a standard deviation of 2.3 meters with normal processing. Application of bias removal techniques reduced the mean geoid height difference to 9 cm and improves the self consistency of the results to a		

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standard deviation of less than 1 m. A comparison of the GEOS-3 Geoid is made with the NASA Marsh and Chang 1976 Geoid. The GEOS-3 Geoid correlates well with the larger features of the local bottom topography.